A Model for Autonomous Reconfiguration of Sensing Web Resources

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Topics covered in this talk

- Technical objective: reconfiguring sensor webs
- Approach based on automated planning and execution
  - Hierarchical, model-based workflow generation and execution
- System overview
- Component description
- Status and future work

Sensor Web Configuration

- An Earth Science *Sensor Web* is a distributed, coordinated system of sensors, models, humans, data sets and data repositories.
- Humans *configure* sensor webs to answer science questions, or for disaster management.
  - Webs are (re)configured through a series of commands or requests.
- Web configuration can be time-consuming and difficult for humans to perform.
  - Requires managing a complex, distributed system.
- Automation can offer benefits in the process.

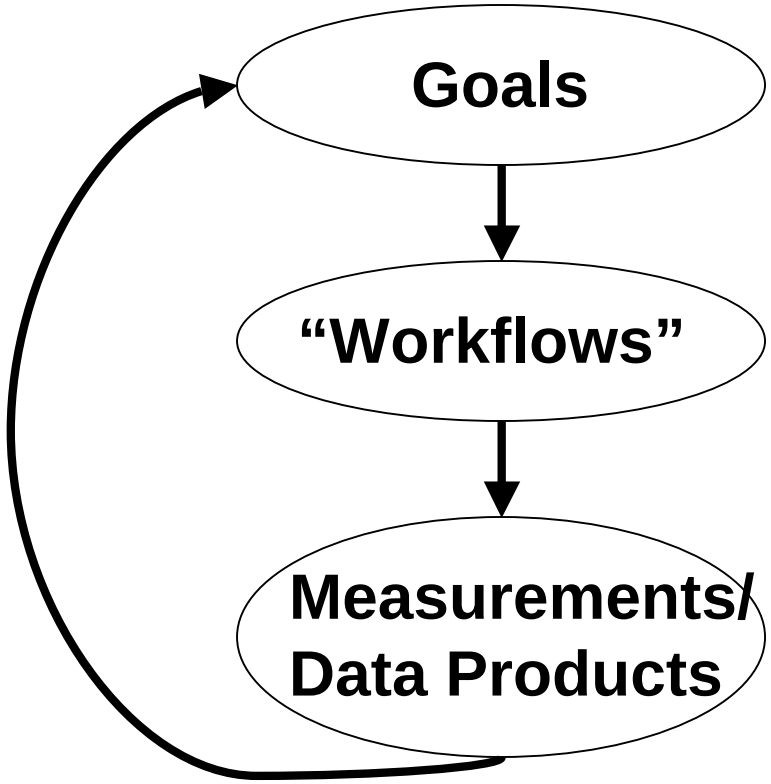
Requirements for Automation

- Improve accessibility to web resources
  - Coordination of resources
- Demonstrate improvements in quality of data
- Generality:
  - Improve the process of data acquisition for any Earth science focus area
- Robustness:
  - Adapt to changes in resource availability during the (re)configuration process.
- Abstract acquisition details from user
  - Define goals at a high level of abstraction

Summary of Approach

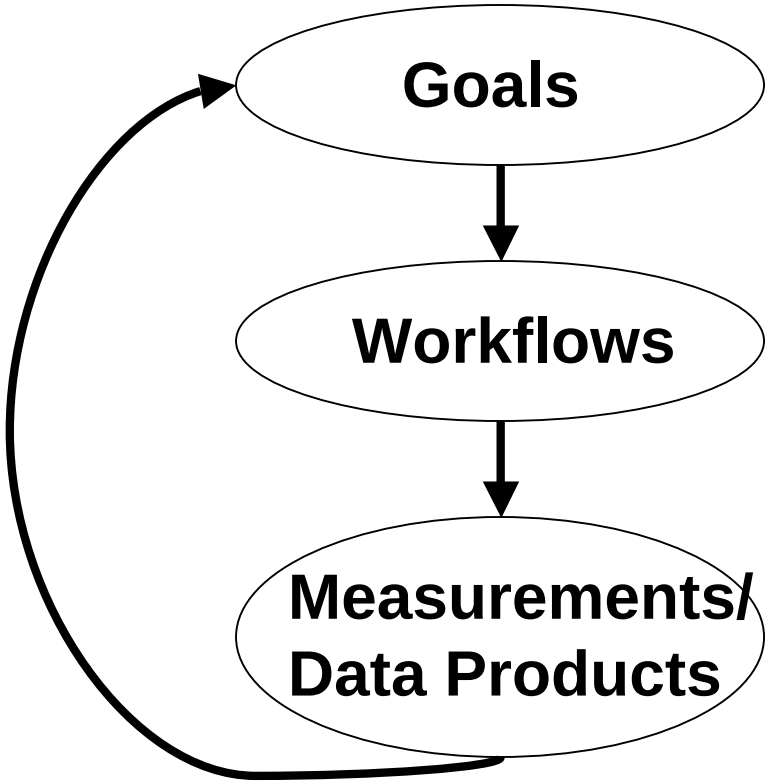
- XML-based goal specification
  - Specifies constraints on data product, workflow
- Automated model-based workflow generation
  - Process based language for composing workflows
- Automated workflow execution
  - Hierarchical model of workflow (abstract, concrete)
  - Executable workflow as a finite state machine
- Leveraging OGC/SWE service layer
- Testbed for demonstrating ideas using Terrestrial Observation and Prediction System (TOPS)

The Data Acquisition Cycle



Workflows are plans for reconfiguring a sensor web to achieve goals.

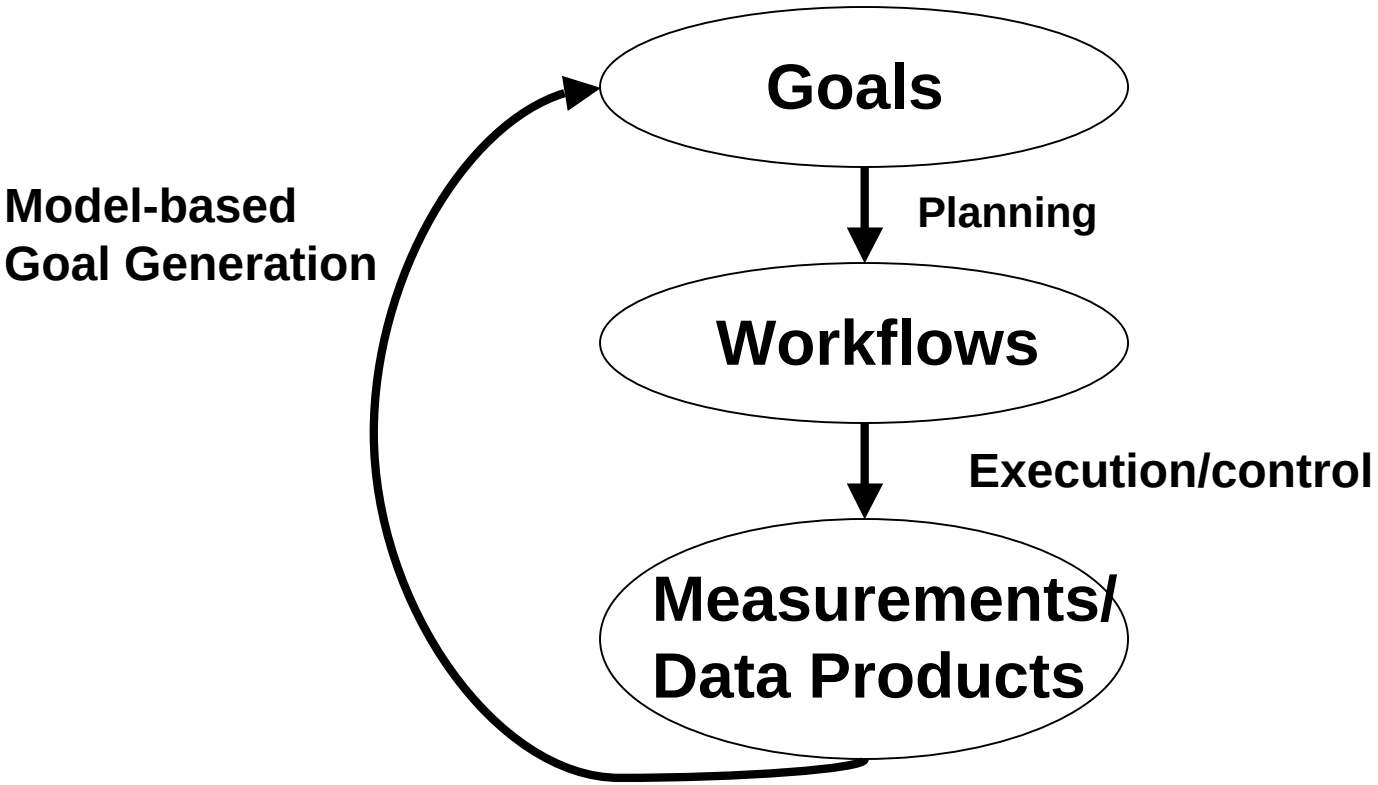
Example



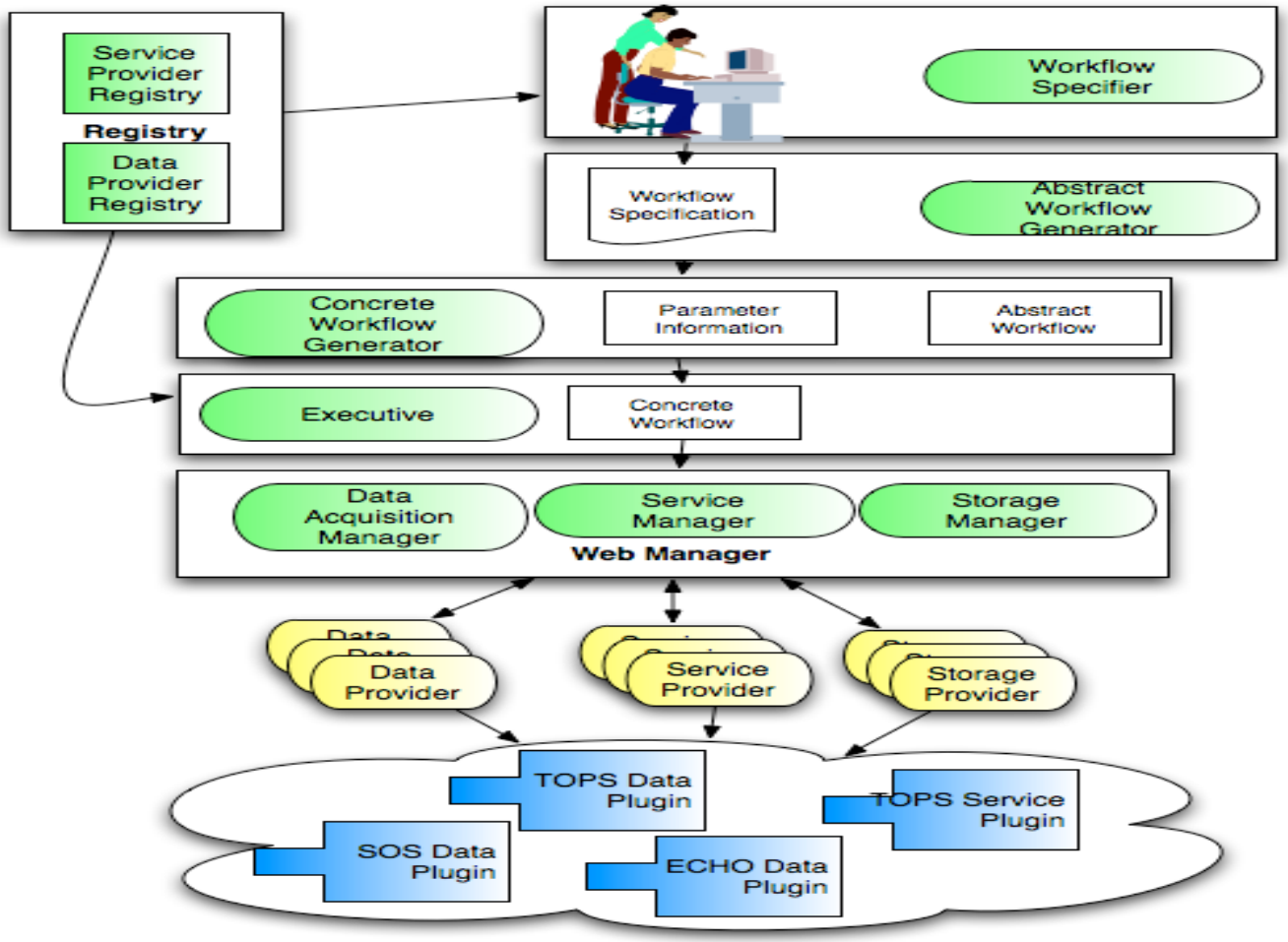
Goal: ***Characterize*** *vegetation for a specified region during 2006 using MODIS data.*

Workflow: ***Get*** *MODIS leaf area index (lai) data between 01/01/2006 and 12/31/2006 in a region defined by a bounding box defined by lower corner lat-long <25.00, -110.00> and upper corner lat-long <40.00, -125.00> and* ***process*** *them every month using the average.* ***Store*** *the measurements into hdf files on the FTP site.*

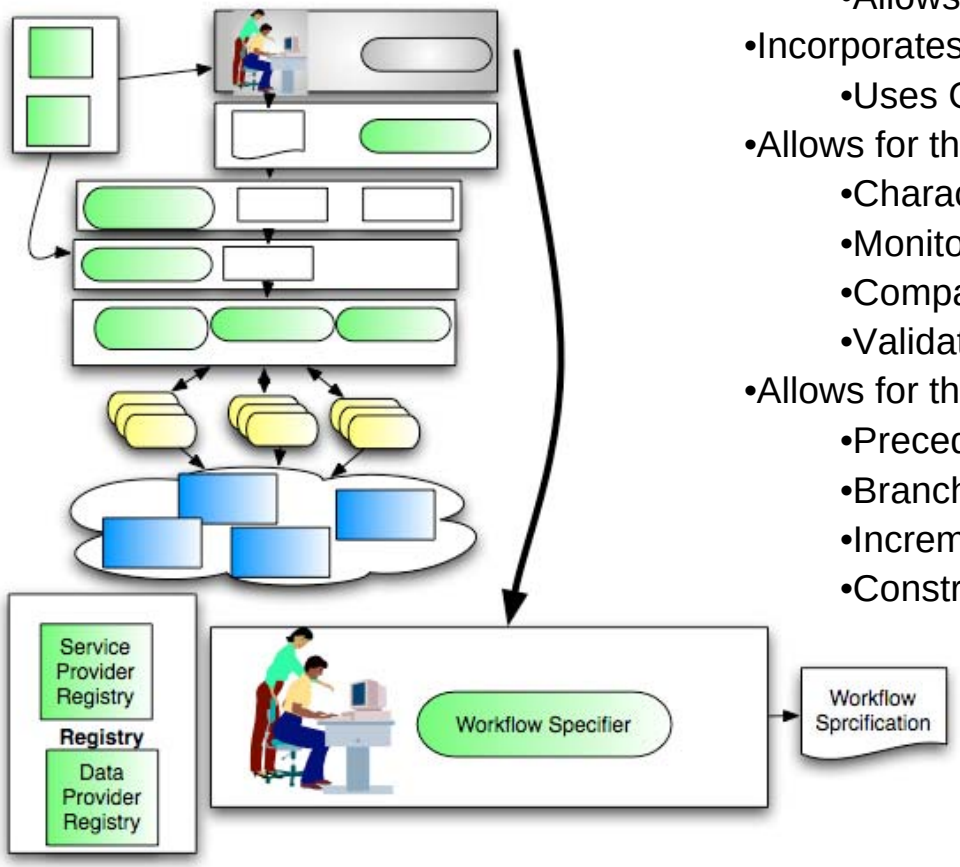
Relevant Software Technologies



Layered Architecture



Workflow Specification

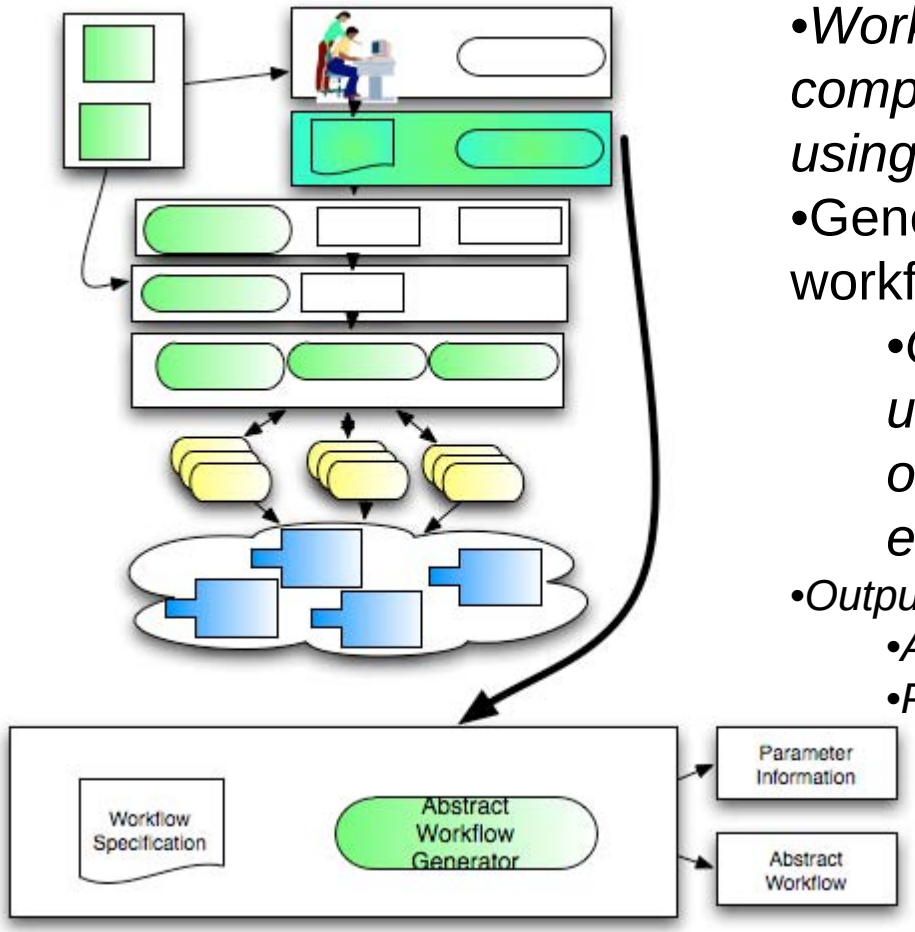


- Goals are expressed using a markup language (GoalML)
  - Facilitates information description in a nested structure
  - Allows tools for validation and parsing to be used
- Incorporates and extends Geography Markup Language (GML)
  - Uses GML spatial and temporal model
- Allows for the definition of workflows for different science goals
  - Characterizing/classifying/Mapping
  - Monitoring an event or measurements over time
  - Comparing/Conflating data sets
  - Validating sensors
- Allows for the definition of constraints on the workflow
  - Precedence and other temporal constraints
  - Branching on results of actions, events in the world
  - Incremental retrieval (staged processing)
  - Constraints on data quality

Goal Taxonomy

- ***Compare*** *the current year's annual net primary production (NPP) map for North America with the 25-year long-term average NPP.*
- ***Monitor*** *daily sea surface temperature for the Gulf of Mexico for 2000-2006*
- ***Map*** *land cover types in 2001 for the state of Sonora, Mexico using the International Geosphere-Biosphere Programme (IGBP) global vegetation classification scheme from the MOD12Q1 product.*
- ***Predict*** *monthly NPP for North America in 2010 using the prognostic BGC model in TOPS.*
- ***Validate*** *the GLOBCARBON leaf area index product for June, 2005, with measurements made at Fluxnet Tower loctions in Canada.*
- ***Compare*** *MOZART model predictions of CO concentrations in an area around Fairbanks Alaska with Observations taken by AIRS. If the predictions diverge from the observations by more than a certain amount,* ***characterize*** *the CO concentrations for the same area for tomorrow. (Composite goal)*

Workflow Generation



- *Workflows are **finite state processes** composed from a small set of basic **tasks** using a small set of **operators**.*
- Generation Algorithm: Enables automatic workflow composition
  - *Composes workflows from **goals** using a model consisting of rules for composing workflow elements*
- *Output of generator consists of*
  - *Abstract plan (workflow constraints)*
  - *Parameter information (constraints on product)*

Workflow Generation from Goals

- Hierarchical workflow representation
- *Abstract workflow:* defines workflow structure without referring to specific resources for task execution.
  - Provides flexible way to define workflows without being concerned with low-level details.
  - Tasks are portable and can be mapped at run time to suitable web services
- *Concrete workflow:* a binding of tasks to resources
    - Tasks move data around or deliver data products to user

Composing Workflows from Goals using a Process Model

- An abstract workflow is described in terms of a *Finite State Process (FSP)*
  - An FSP describes the execution of a sequence of basic tasks
  - Two kinds of basic tasks: data acquisition and "staging"
    - Data acquisition tasks include *get, process (data), store.*
    - Staging tasks allow for the workflows to be autonomously executed and monitored.
      - Example: test whether a server is available
      - Test whether data is ready to be acquired.

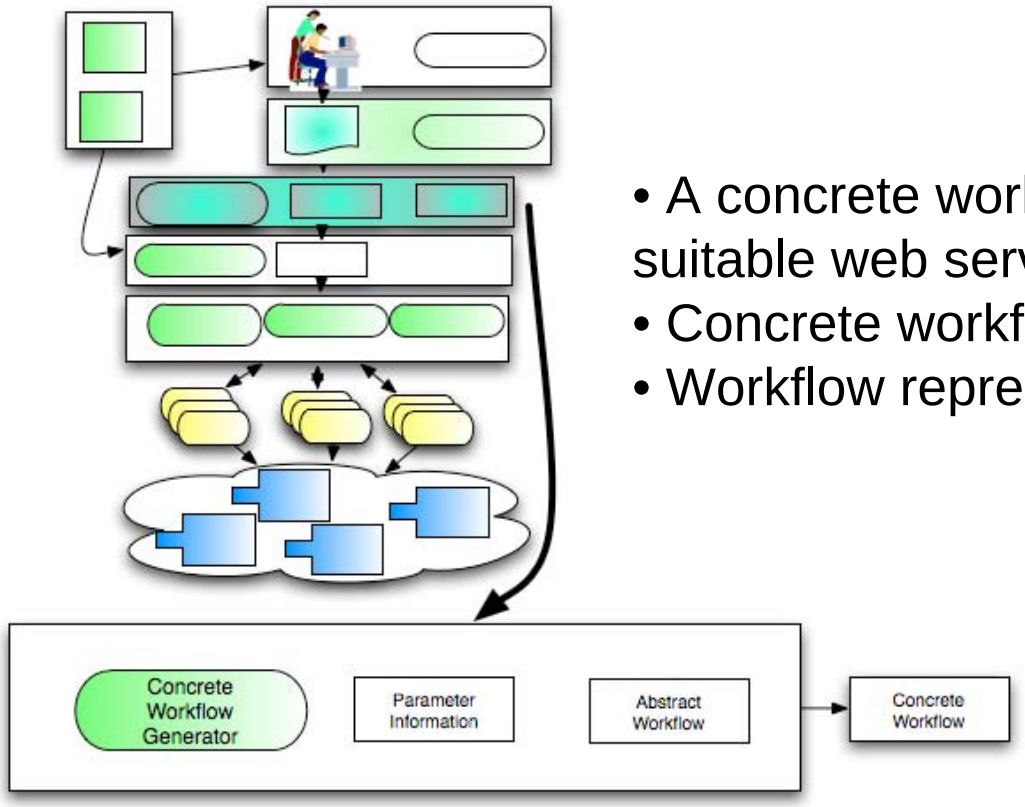
Composing Workflows from Goals using a Process Model

- Operators for composing workflows: If *P,Q* are processes and *a,b* are basic actions, then
  - **Sequence:** *a --> P* is a process
  - **Choice:** *(a --> P | b --> Q)* is a process
  - **Recursion:** *P: a --> P* is a process
  - **Non-determinism:** *(a --> P | a --> Q) is a process*
  - **Parallelism:** *(P || Q)* is a process.
  - **Instance/type:** P1:P P1 is a process of type P
- Implementation using Labeled Transition State Analyzer (LTSA) system
  - Verification tool for concurrent systems

Simple Abstract Workflow

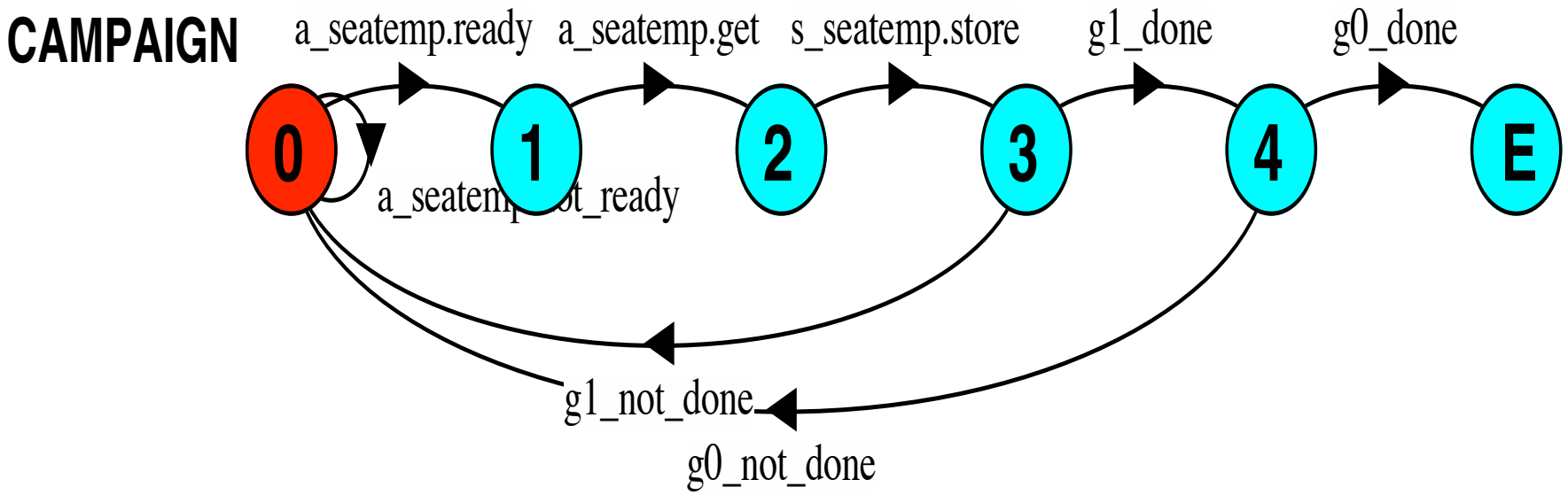
```
//Declaration section
ACQUISITION = (ready -> get -> END | not_ready -> ACQUISITION).
PROCESS     = (process -> END).
STORE       = (store -> END).
TEST        = (test -> (test.true->END | test.false->END)).

//Goal#0
                //Goal#1
                 //components:
                    ||A_SEATEMP = (a_seatemp:ACQUISITION).
                   ||S_SEATEMP = (s_seatemp:STORE).
                 //workflow:
                      G1_WFC1          = A_SEATEMP;S_SEATEMP;END.
                      ||G1_ONCE        = (A_SEATEMP||S_SEATEMP||G1_WFC1).
                      G1_REPEAT        = G1_ONCE;G1_TEST4DONE,
                      G1_TEST4DONE     = (g1_done -> END | g1_not_done -> G1_REPEAT).
                      ||G1             = (G1_REPEAT).
 //Workflow:
      ||G0_ONCE     = (G1). //Parallel composition of components and workflow constraints
      G0_REPEAT     = G0_ONCE;G0_TEST4DONE,
      G0_TEST4DONE = (g0_done -> END | g0_not_done -> G0_REPEAT).
      ||G0          = (G0_REPEAT).

||CAMPAIGN = (G0).
```

Concrete Workflow Generation



- A concrete workflow binds acquisition actions to suitable web services at run time.
- Concrete workflows are *executable*.
- Workflow represented as a finite state machine.

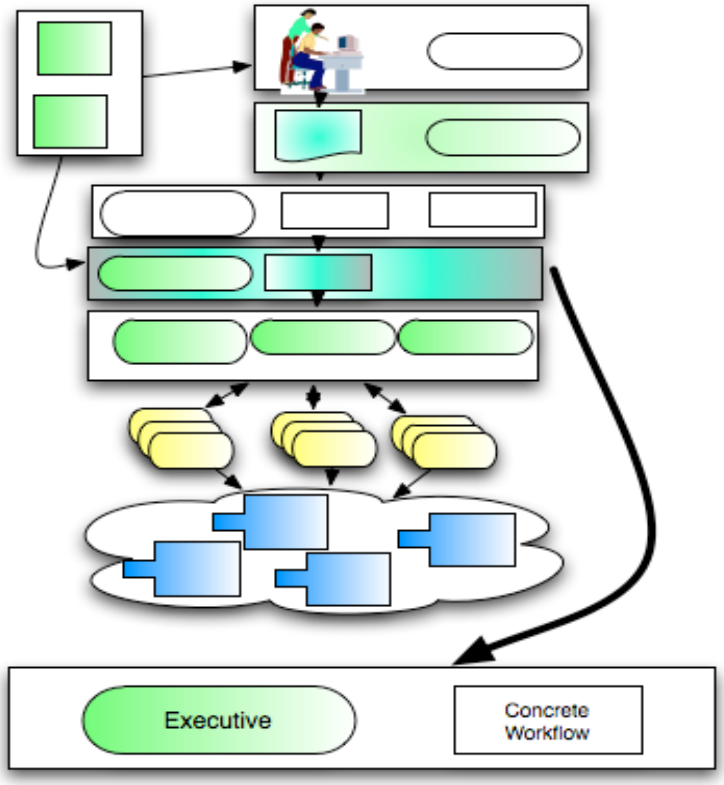
Workflow as a Finite State Machine



Concrete Workflow Generation

- Combines abstract Workflow in the form of finite state machine with concrete instantiation of the GoalML document
- Utilizes schema that describes the structure of the Goal language
- Translation of the schema to java implementation using the Java Architecture for XML Binding (JAXB)
- In addition, integrates the following from OGC templates:
  - OGC Geographic Markup Language (GML)
  - OGC Sensor Web Enablement Common Data Model (SWE-Common)
- Currently over 220,000 lines of code and more than 1100 java classes
  - Ability to process and validate *any* GoalML, GML and SWE-Common documents
  - Used the experience to derive bindings for SensorML
  - Will be also useful for Sensor Observation Services and other standards

Workflow Execution



- Executes a workflow as a finite state process.
- Monitors progress of execution, enables tolerance to execution failure (robustness)

Workflow Execution

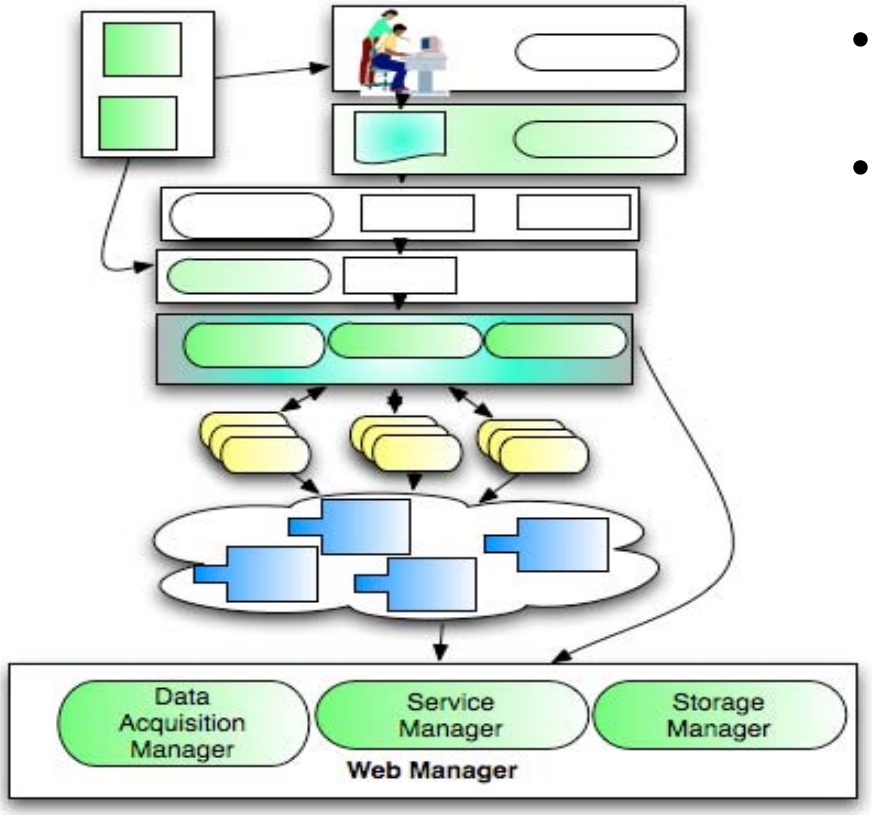
Algorithm:

- Incremental composition of **concrete workflow** out of **abstract workflow** and **procedure mapping** function.
- Concrete workflows are executed by incrementally mapping basic tasks in an abstract plan to requests for web services.
- Observation of progress towards goals.

Representation:

- Finite state machine-based representation of workflows
- Coordination with Web Manager to perform mapping

Web Manager



- High level interface to web service layer
- Consists of three main components:
  - Data Manager
    - Provides access to the sensor web data
  - Service Manager
    - Provides access to services (processes) - local or remote
  - Storage Manager
    - Provides access to storage (filesystem, database)

Data Management

- *Data Manager* manages a collection of *Data Providers*
- *Data Provider* consists of an entry point (e.g. location on the web, such as address and a port) and *Data Service*
- *Data Service* is an interface that provides generic view of any data service
  - Users and developers can implement any service they want/need as well as reuse existing *Data Service* implementations
  - TOPS, ECHO, Sensor Observation Services, …
  - Flexible architecture, so they can be loaded in runtime without any change to the system code or the need to re-compile
  - Advantage when designing architecture for unknown future services

Process Management

- Similar flexible architecture with plug-in services
- Ability to handle both local and remote services,
  - Works across styles/protocols such as REST, SOAP, CORBA, etc. - the particular plug-in will handle the low level details
- Currently using SensorML process model to describe local processes and the constraints on their inputs and outputs
  - May not be always available and we would like the ability to interface other systems without having to force SensorML on the users

Integration into TOPS

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TOPS is a data and modeling software system designed to seamlessly integrate data from satellite, aircraft, and ground sensors with weather/climate and application models to produce operational nowcasts and forecasts. TOPS operates at a variety of spatial scales, ranging from individual vineyard blocks to global monthly assessments of vegetation net primary production.

MODIS Aqua Image of San Francisco Bay, 18-Jun-2008

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Status and Future Directions

- Integration and testing
  - Demonstrating end-to-end capabilities on numerous use cases
  - Using TOPS as initial test bed.
- Distributed planning and execution
  - Leverage modularity of process-based approach
- Managing uncertainty in execution
- Deployment in distributed applications

Summary

- Developed a model of reconfiguring sensor webs using principles from autonomous workflow planning and execution
- Emphasis on
  - generality of approach
  - Abstraction for greater flexibility
- Model-based workflow generation
- Framework for autonomous execution of workflows in conjunction with service layer